Performance Evaluation of Home Health Care Assistant Platforms: Simulation Study

R. Kalvandi and Y. Maddahi

***Abstract*—**Technical aids allow elderly and handicapped people to live independently in their private homes as long as they wish. The most popular technologies, employed to help these people, are intelligent and programmable platforms, which are called home care assistant robots. This paper discusses the background and performance assessment of autonomous platforms used in home to assist human in performing their activities. The evaluation is carried out using six indices focusing on performance of machines during motion. The indices represent the motion ability of each platform along straight/curvature trajectories, occupied space during direct movement and turning, daily energy consumption, stability of platform, as well as the level of platform safety when it is in contact with human. Totally, four different mechanisms are evaluated in which the driving system and wheels differ from each other. Simulation study on considered mechanism indicates that the platform with omnidirectional mechanism performs best as compared to the two-wheeled, differential drive, and caterpillar mechanisms. The authors believe that using the proposed procedure to evaluate the mobile platforms has the potential to advance our understanding of human-machine interface design as well as have the possibility of using these mechanisms to help patients get cured faster and feel comfortable in performing tasks.

***Keywords*—**Home care, Assistanting machine, Human's safety, Performance evaluation, Risk assessment.

I. Introduction

RAPID developments of medical technologies in the last twenty years have greatly encouraged researchers in the use of medical machines for surgery, diagnosis, rehabilitation, and prosthetics, as helpful tools for disabled and elderly people. Imagine a scenario in the near future in which intelligent machines will communicate with humans, and conduct medical procedures, especially those that presently assigned to general practitioners. This scenario could be a reality in our lives, particularly for elderly people possessing intelligent robots, as personal care assistants that provide reminders of things like appointments, medications and exercises.

Assistive technologies for mentoring in homes constitute a promising opportunity to decrease load on the health care system, reduce hospitalization period, and improve quality of life. Many research studies have been performed in order to investigate the possibility of the use of autonomous machines in treatment of elderly people or children as well as to help the disabled people work more comfortable. For instance, the researchers at the University of North Carolina [1], hoped that a medical platform provides the required stimulation to reinforce the autistic child's responses. Moreover, it was hoped that the mobile platforms allow the child to relax and view the activity as play and to reduce social anxiety. Indeed, it was believed that the autonomous machines bridge the gap between the inner world of the autistic, and the unpredictable but necessary teacher.

Kazuyoshi *et al.* [2] investigated the possibility of using human-made platforms, to rehabilitate disabled children. The investigation of what constitutes a successful social interaction has long been pursued separately by human psychologists, linguistic analysts, engineers, and animal behaviorists. Similarly, they used mental commit robots to observe their psychological effects on elderly people at a day service center [3]. The results exhibited positive psychological, physiological, and social effects on elderly people interacting with the prototyped medical robots. Along with that, Tatsuya *et al.* [4] performed a set of experiments in order to investigate how human's attitude can quantitatively be measured using psychological indices. Experimental results showed attitudes toward assisting robots highly depend on difference in attitudes between different assumptions about robots originated from culture, difference in attitudes toward particular type of robot, and difference prejudgments about robots. In another study, Shibata *et al.* [5] addressed purposes, background, and current status of an artificial emotional creature project in which a pet robot was used to investigate psychological effects on human through human-robot interaction.

The design and implementation of movable platforms should therefore appear to be a new and interesting area, while enlarge the interactive and communication skills of the individual human through the enjoyable medium of play. The current research work extends the work [6], previously performed by the authors, on the mobile robots operate as assisting robot, and aims at developing mobile platforms to be employed in hospital environment to help the patients get cured faster and enjoy when they do their own tasks. The work aims at showing how robots are able to make a valid contribution in the process of rehabilitating patients especially the elderly people. The authors report that the platforms, especially mobile ones, have the potential to make a

Manuscript received October 08, 2012.

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contribution in area of rehabilitation of patients, while provides enjoyment for them. With reference to mentioned literature, it is demonstrated that implementing mobile platforms in rehabilitating people who are suffering from lack of proper communication or mental illnesses, is possible. However, literate on real applications of this kind of platforms is scares, and needs to be more practically investigated.

In particular, this study presents development and evaluation of four mobile platforms with different mechanisms. All platforms are practically implementable, and designed to evaluate their effectiveness by performing some scenarios of simulations using ADAMS software. The performance of each platform is investigated under six criteria representing their workability. The platforms consist of a two-wheeled mobile platform, a differential drive mechanism, a platform with caterpillar mechanism, and an omnidirectional vehicle. The simulation studies show that omnidirectional platform is the most efficient mechanism. The safety assessment is performed in order to observe how safe the platform work when it is in contact with human. The assessment is carried out using the Failure Modes and Effects Analysis (FMEA) method which is an inductive failure analysis used in product development, and system reliability of systems [6].

The organization of paper is as follows. The performance criteria are described in Section II. Section III explains the structure of designed platforms, followed by presenting some typical applications of these platforms. Section IV covers the simulation results performed on four mechanisms. The conclusions and future work are addressed in Section V.

II. Evaluation Indices

In order to present proper service to patients, each platform is designed to perform various tasks in different situations. In the other words, the platform should be able to have access in most of places inside the home which results in having the capability of moving along various paths. A typical trajectory, along which the platform moves, is shown in Fig. 1. In this figure, the platform travels along a combined path from the “START” point towards the destination (“END” point). To reach the final point, the platform should be capable of moving along all straight, curvature, and multiple-line paths.

In all experiments, designed to examine each platform, the initial and final positions and orientations of the platform are given to the platform using the ADAMS software. Afterward, the platform travels from the start point to the destination point. Using this technique, the efficiency of each platform is evaluated based on it’s path tracking ability. Moreover, some other performance indices are defined to investigate its workability. The comparative evaluation is performed based on six performance indices. They are:

Index I: Ability of platform in travelling along straight forward trajectory which shows its performance during movement in corridors and spaces in which there is no obstacle or turning ahead (see sub-path A in Fig. 1).

Index II: Capability of platform in turning clockwise and counter clockwise representing the ability when it is programmed to change the direction and turn along its central axis, *e.g.* turning at the end of a corridor. A typical example is depicted in Fig. 1 (sub-path B). This index can also be used as a measure to determine how much space is occupied by the platform during turning.

Index III: This index represents performance of machine in changing the paths and is a combination of first and second criteria. Since most of assigned tasks to machine are given as combined tasks and the machine has to change its path without reprogramming, this index is considered as one of the important indices, especially when the machine is programmed to do multiple tasks in the home environment (sub-path C in Fig. 1).

Index IV: Next measure is the energy that the platform consumes for the specific and defined task. This criterion is important when the platform is supposed to perform some desired tasks with limited amount of energy. This measure is estimated based on the number of motors normally required to move the platform. Clearly, the machine with more number of motors consumes higher energy as compared to the machine having less actuators.

Index V: Stability of the platform during the motion is measured by using a measure called stability area which is the area of surface obtained by connecting the wheels contact points with the ground. Figure 2 illustrates two typical examples of stability area belong to a four-wheeled and a three-wheeled platforms. As observed, both platforms have the same dimensions. However, the shape combined by connecting the wheels contact points (solid circles) in Fig. 2a has an area more than Fig. 2b which indicates that mechanism (a) is more stable than mechanism (b) in motion. This technique is used to evaluate the stability of tested platforms.

Index VI: The level of safety that the platform has when it is in contact with the patient in a medical environment is considered as the last criterion. The unsafe situations usually

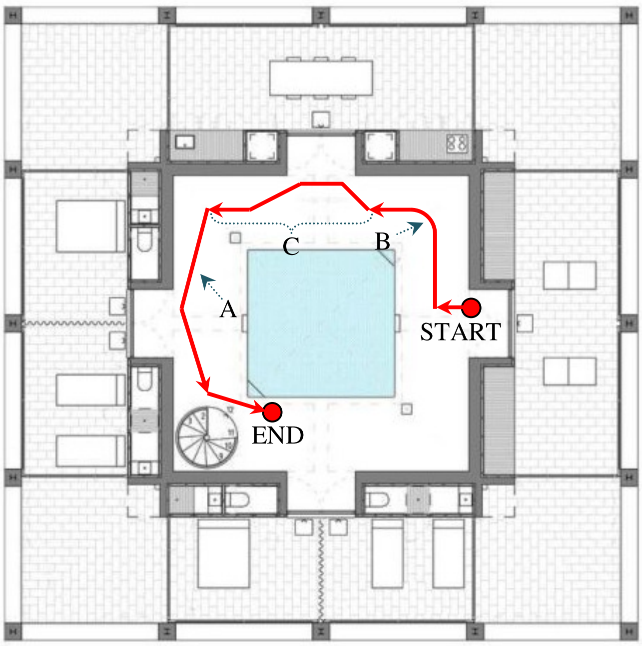
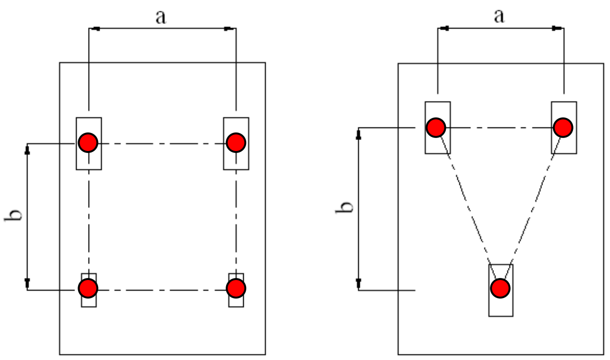


Fig. 1. Typical applicable tasks for a home care assistant machine.



(a) (b)

Fig. 2. Stability area for two mechanisms having the same dimensions.

occurs due to inappropriate design or improper selection of materials. Here, the FMEA method is employed to reduce the intensity of risks. The FMEA helps the platform perform the task at the desired level of risk. The possible risk is assessed by defining a quantitative measure called Risk Priority Number (RPN) [7]. The RPN is calculated by implementing three rating factors: *Severity* (S), which rates the severity of the potential effect of the failure, *Occurrence* (O), which rates the likelihood that the failure will probably occur, and *Detection* (D), which rates the likelihood that the problem will probably be detected before it is used by the patient. The rating factors range from 0.1 to 1, which the higher number representing the higher seriousness or risk. For example, *Occurrence*=1 indicates that the failure is very likely to occur and is worse than *Occurrence*=0.1, which shows that the failure is very unlikely to occur. For each possible risk, the RPN is calculated by multiplying the rating factors, i.e. PRN=S×O×D. The RPN is used to rank the risk priority in platform design and has the value between 0.001 and 1.

To start the risk assessment using the FMEA, for each component, all potential failure modes are firstly analyzed and severity, occurrence, and detection factors are obtained from standard criteria. In our tests, the failure modes, whose risk number is high (PRN≥0.15), are known as critical failure modes and the corresponding components make the system risky. Thus, the critical components need to be modified/removed in order to reduce risks and hazards for the platform.

III. Designed Platforms

A. Structures

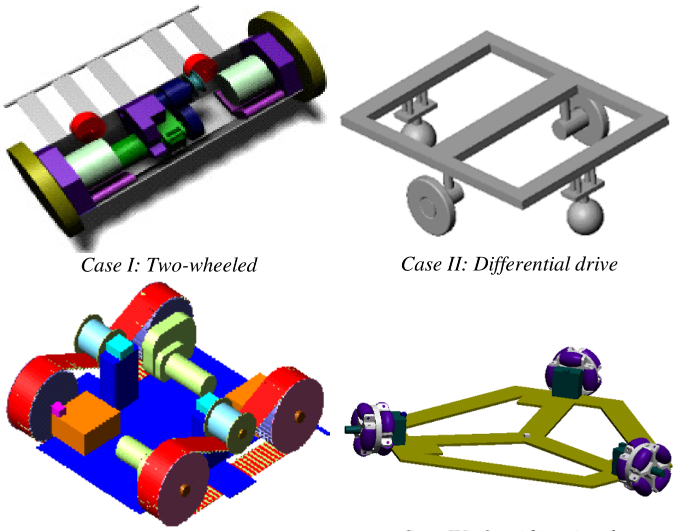
This section describes all four mobile platforms that are used as the mobile base of hospital care assisting machines.

Case I: Two-wheeled mechanism: With reference to Fig. 3a, the two-wheeled platform consists of two driving wheels which provide the driving power required to move robot. The platform is suitable for environments in which the problem of space limitation exists.

Case II: Differential drive mechanism: The differential drive platform has two driving wheels and two free castor wheels (see Fig. 3b). This mechanism is usually used for situation with enough working space and is more stable than Case I. The considered mechanisms help the user easily program the machine for a variety of applications.

Case III: Caterpillar mechanism: As shown in Fig. 3c, the driving mechanism of Caterpillar consists of two driving and two castor wheels. The wheels are constructed with flexible rubber to create enough friction during the motion.

Case IV: Three-wheeled omnidirectional mechanism: As depicted in Fig. 3d, this platform is composed of three Sweden driving wheels with their own driving systems which are independently driven by three motors. The omnidirectional wheels are centered on the longitudinal axis of the vehicle. These wheels are driven by non-steering wheels powered by independent mechanisms and have single-row roller arrangement (see Fig. 3d).



Case I: Two-wheeled *Case II: Differential drive*

Case III: Caterpillar *Case IV: Omnidirectional*

Fig. 3. Examined mobile platforms.

Table I illustrates key specifications of the platforms described above. The simulated models were designed based of the prototyped robot, which were manufactured by the authors [8, 9].

TABLE I SPECIFICATIONS OF SIMULATED PLATFORMS.

	Case I	Case II	Case III	Case IV
Dimension (L×W×H) (cm)	10×10×22.5	18×32×14	20×20×18	28×28×9
Weight (kg)	0.880	3.280	1.80	0.450
Maximum linear speed (m/min)	0.115	0.230	0.210	0.270
Wheel radius (cm)	5.0	5.5	1.3	3.5

B. Applications

All four platforms are designed to operate on the floors of assisted living facilities, eldercare facilities, healthcare facilities, hospitals, or at homes. The platforms can enable assisting machines to do several tasks including:

- Autonomously navigating through an assisted living facility, a hospital, an eldercare facility or a home,
- Monitoring health monitoring of patients on a regular basis: take blood pressure, measure body temperature, heartbeat rate, heartbeat irregularities, and pulse oximetry.

- Submitting the medical data into a centralized medical IT system over wireless network,
- Detecting people lying on the floor, or call for help,
- Reminding about the need to take the medication,
- Communicating the elders from time to time, check that everything is okay, and call for help in case of a trouble,
- Providing remote video and audio connections for the care-givers and doctors,
- Delivering meals, collect dishes, and deliver plates to a dishwasher location,
- Transport objects to certain locations,
- Guide the elders around the place, escort guests, and providing guidance,
- Recognize patients by voice, face, or name,
- Act as a security robot in the night, detect intrusions, and call for help,
- Detect fire and smoke, and call for help,
- Entertain the patients.

IV. Performance Evaluation

A. *Test Procedure*

The simulation results are obtained using four measures: (*i*) the average of position error that the machine has along the paths considered for indices I, II, and III, and (*ii*) estimating the energy required to run the robot, (*iii*) measuring the stability area, and (*iv*) assessing the level of risk.

In order to set up the simulation study, the modeled platforms are programmed to move along a straight (index I), circular (index II), and combined (index III) paths, using the Adams software. The average movement errors are then measured in order to quantitatively measure the accuracy. Then, the power consumption, which is directly related to the number of actuation systems, is estimated. The stability area, for each case, is measured using characteristics presented in Table I, and definition explained in Section II (see Fig. 2). The mean value of the PRN representing the amount of risk threating the patient is also calculated using FMEA method (described in Section II). All simulations are done under same test conditions, thus, the results are comparable on the same boat.

B. *Experimental Results*

To evaluate the behavior of machine under the first index, the platform is programmed to move along a straight trajectory with the length of 1 m, and the deviation of each platform from this desired path is measured and recorded. In first set of tests (straight path), the desired position center is given to each platform to go there. By computing the position error, which is obtained by subtracting the desired (ideal) and real stop point (actual) points, we can find how accurate the platform is able to move along straight trajectory. The desired trajectory is shown by dashed line (red line) in Fig. 4, which starts form "A" and ends to "B".

In next experiment, the accuracy of platform is measured while each machine is programmed to rotate by 90° in clock wise direction. The curve is located on horizontal plane *i.e.* the height of the platform is constant from the earth level. The desired trajectory is shown by dotted line ("E" to "F").

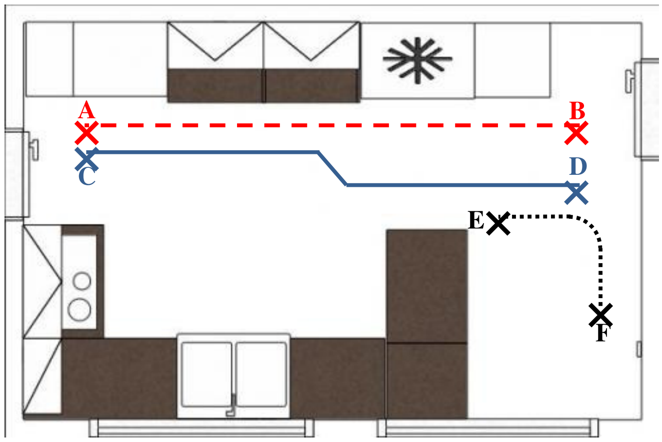


Fig. 4. Considered trajectories to evaluate performance of each platform under indices I (dashed line, red), II (dotted line, black), and III (solid line, blue).

The third set of tests focuses on performance evaluation of each platform when it changes the movement trajectory, i.e. travels from a path to another one. The typical path is illustrated in Fig. 4 by solid line when each platform goes from point "C" toward "D".

In all three sets of experiments, the quantitative measure, used to compare the workability of mechanisms, is the mean value of position error occurred at the end of the trajectory. The position error represents the accuracy of platform along the corresponding path.

Figure 5 depicts the mean value of position errors, occurred during the motion. The amount of position error are expressed by normalized values, in which the measured values, on different scales are adjusted to a notionally common scale, often prior to averaging. As observed, in all three simulation studies, Cases II and III showed the worst behavior in terms of position error, while Cases I and IV exhibited reasonable responses.

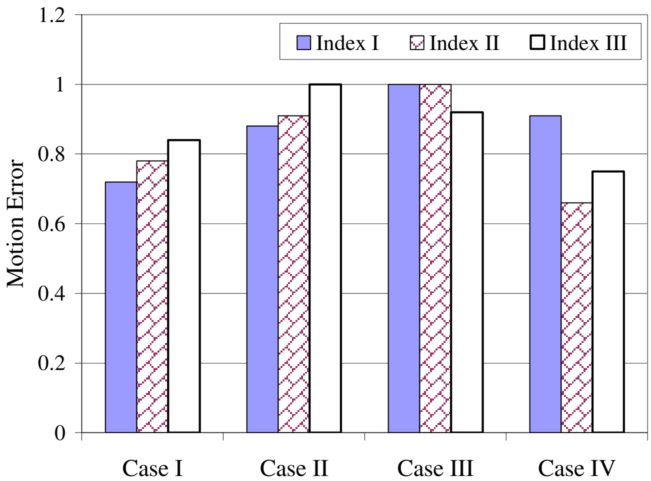


Fig. 5. Normalized values of position error along paths defined to evaluate performance along straight line (index I), curvature line (index II), and multiple line (index III).

Figure 6 illustrates the mean value of task completion time, obtained from the software during testing the performance of robot according to Indices I, II, and III. As shown, Case III travelled the path slowest than the other cases. On the other hand, Case I is faster than Cases II and III. The task time has not been considered as a performance index, but it, in future, can be taken into account as an index for cases in which the speed of the platform plays a key role.

With respect to Index V, the simulation analysis showed that the amount of consumed energy can be measured from the measured torque in the software. The torque, required to move the platform, is in direct relation with the consumed energy. The normalized values of motors torques are illustrated in Fig. 7. As observed, Case I is the most efficient mechanism in terms of energy consumption. This measure is more important when the platform is employed in the areas with lack of energy resources.

The stability areas of platforms, calculated based on the characteristics in Table I, are shown in Fig. 8. As depicted, Case III is very stable as compared to the other cases. Also, since the Case I has only two wheels, the stability area, for this case, will be zero, which shows that this platform is not suitable for situations requiring stability, such as delivering meal, collecting dishes, and transporting the objects.

In order to evaluate the level of risk in each platform, the high risk components of each platform are recognized and the corresponding PRN is calculated [7-9]. As mentioned, the higher value of PRN is, the more hazardous the platform will be. The mean values of PRN, for each mechanism, are shown in Fig. 9. As observed, Case II exceeds the allowable level of PRN, mentioned in Section II. Therefore, this platform cannot be considered as a home care assisting mechanism due to the possible risk it might create for patients.

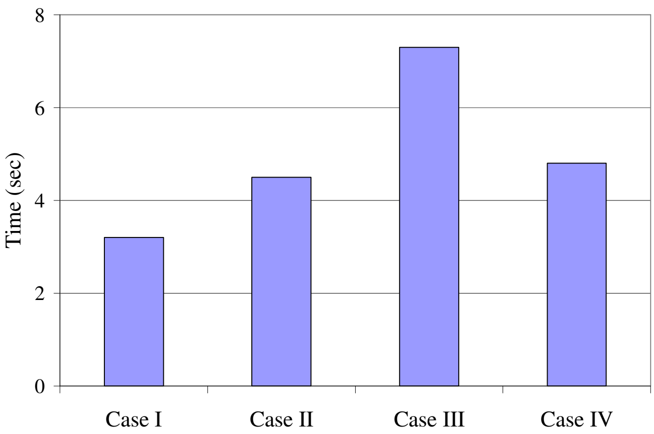


Fig. 6. Mean value of task completion times for all simulated platforms.

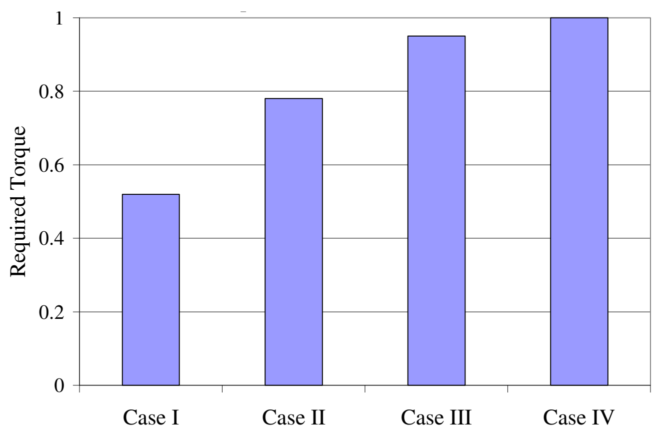


Fig. 7. Required torque to run the platforms in the software.

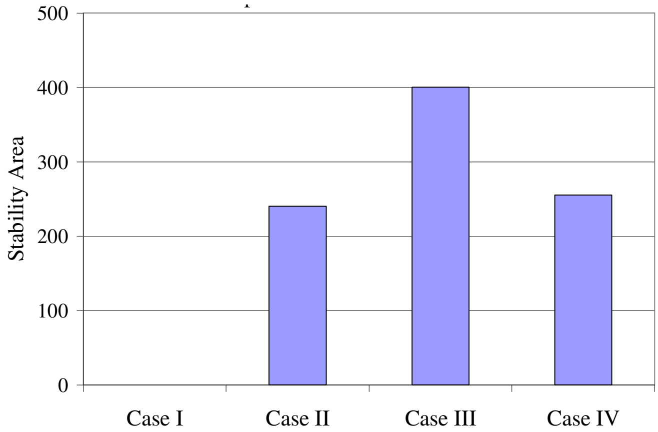


Fig. 8. Stability area of platform (in cm^2).

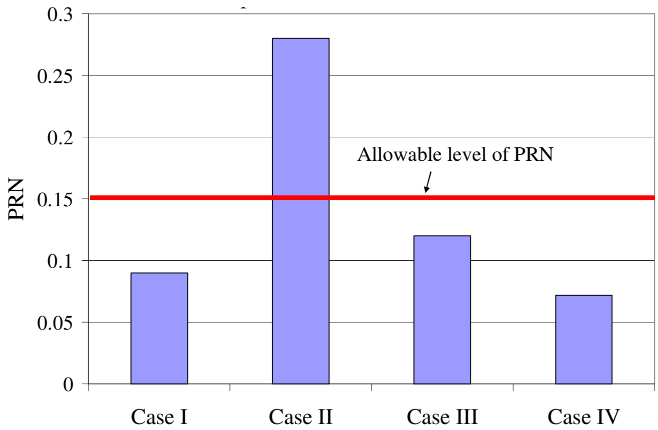


Fig. 9. PRN values calculated using FMEA method.

Considering the results, obtained in this section (Figs. 5 to 9), it is concluded that the omnidirectional mechanism (Case IV) showed the best behavior in terms of the proposed indices. Moreover, this mechanism is more safe than the other ones (see Fig. 9), which is a very important factor when the machine is in contact with patients.

V. Conclusions

The literature reviews, on home care assisting technology, showed that the idea of using mobile machines is not a novel proposal. However, the implementation of these systems, in treatment of elderly people, is a challenging work in real world. This work presented a comparative study of the mobile platforms, used to help patients perform their own activities, under six technical criteria. The criteria were: (*i*) ability of platform in moving along straight path, (*ii*) ability in traveling along curvature trajectory, (*iii*) ability in changing the direction from one path to another one, (*iv*) amount of consumed energy, (*v*) level of mechanism stability, and (*vi*) level of risk and hazard when it is in touch with the patient. The performance evaluations indicated that the omnidirectional mechanism is more sufficient than the other platforms in terms of these six criteria. Moreover, this platform exhibited good level of safety in risk assessment analysis. The result of this research is believed to be used as a tool in practical application of mobile platforms in treatment of patient who are not able to do their tasks by themselves. Future work will be on validation of experimental results using the prototyped mechanisms.

ACKNOWLEDGMENT

The authors would like to thank Dr. Robert Summers, from University of Winnipeg, for his instructive advices in this research.

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